Alexandria Engineering Journal (2015) 54, 881–888

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Alexandria University

Alexandria Engineering Journal

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ORIGINAL ARTICLE

Influence of injection timing on DI diesel engine characteristics fueled with waste transformer oil

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Received 24 November 2014; revised 23 June 2015; accepted 22 July 2015
Available online 11 August 2015

KEYWORDS

Waste transformer oil;
Injection timing;
Diesel engine;
Emission;
Trans-esterification

Abstract This research work targets on the effective utilization of WTO (waste transformer oil) in a diesel engine, which would rather reduce environmental problems caused by disposing of it in the open land. The waste transformer oil was compared with the conventional diesel fuel and found that it can also be used as fuel in compression ignition engines since the WTO is also a derivative of crude oil. In this present work, the WTO has been subjected to traditional base-catalyzed trans-esterification process in order to reduce the high viscosity of the WTO which helps to effectively utilize WTO as a fuel in DI diesel engine. The objective of the work is to study the influence of injection timing on the performance, emission and combustion characteristics of a single cylinder, four stroke, direct injection diesel engine using TWTO (trans-esterified waste transformer oil) as a fuel. Experiments were performed at four injection timings (23°, 22°, 21°, and 20° bTDC). The results indicate that the retarded injection timing of 20° bTDC resulted in decreased oxides of nitrogen, carbon monoxide and unburned hydrocarbon by 11.57%, 17.24%, and 10% respectively while the brake thermal efficiency and smoke increased under all the load conditions when compared to that of standard injection timing.

1. Introduction

Rapid depletion of conventional fossil fuels, increasing pollution levels by combustion of fossil fuels and their increasing prices make alternative fuel sources more attractive. Petroleum-based fuels are limited reserves, concentrated in certain regions of the world and are shortening day by day [4–6]. Huge amount of dollars is being invested in the search for alternative fuels. Meanwhile, the disposal of waste or used transformer oil from electrical power stations and from the large number of transformers located throughout the country is becoming increasingly complex. Over a long period of time, petroleum-based mineral oils have been used in liquid-filled electrical transformers primarily [24]. It is well known that the transformer oil is employed in the electrical transformer for insulating purpose, additionally, cooling is another purpose of using transformer oil in the electrical transformer while the transformer is in operation. The insulating oil used in electric transformers consists of complex blends of more than 3000 hydrocarbons and all the transformer oil is essentially highly branched aliphatic and aromatic, napthenic or parafenic crudes [31,17] that are extracted or refined and conditioned into hydrocarbon oils.

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.07.008
1110-0168

Conversion of waste-to-energy aims to replace conventional fuels. Fuels such as alcohol, biodiesel, and liquid fuel from plastics are alternative fuels for internal combustion engines [19–21]. Most of the research works are focussed on different waste energy sources such as waste lubrication oil, plastic oils, and tire pyrolysis oil. A large amount of waste energy sources are discharged without utilizing the energy content available in the waste disposals. In this work, the used transformer oils disposed as waste from power generation plant are collected and then refined in order to utilize the available energy content in the waste oils. The disposal of waste transformer oil is also becoming complex since it could contaminate the soil and waterways, if serious spills occur. Government regulatory agents are already looking into this problem and are imposing penalties for spills. Many transformers are located in populated areas and shopping centers. The long term usage of the transformer oil in the power or electric transformer causes some changes in its physic-chemical characteristics [31,17] and makes the oil unfit to be used for insulating purpose in the electric transformer. So the waste transformer oil becomes one of the most important energy sources. The effective utilization of waste transformer oil may reduce environmental problems rather disposing it in the open land. After a proper treatment, waste transformer oil can be used as an alternative fuel in CI engine. The use of transformer oil as a substitute for diesel fuel provides an opportunity to minimize the over exploitation of already depleting natural resources.

Previously studies have been carried out on the utilization of tire pyrolysis oil, waste lubricating oil, and waste cooking oil as an engine fuel substitute. In this regard [22], demonstrated the effective utilization of waste plastic oil, a renewable and biodegradable fuel produced by crackling process, in a diesel engine. Based on their study, reports on reduction in NO_x (oxides of nitrogen), CO (carbon monoxide) and UHC (un-burnt hydrocarbon) emission and increase in BTE (brake thermal efficiency) were documented for waste plastic oil at a retarded injection timing of 14° CA (crank angle) BTDC (before top dead center). Similarly [1], identified that the engine lubrication oil is being discarded as waste and thus, initiated an attempt to utilize it as a fuel for diesel engine. In their venture, DLF (diesel like fuel) was produced from waste engine lubricating oil by pyrolytic distillation method and the measured properties of the produced DLF were found conducive for its use in a diesel engine [26–30]. Subsequently, the experimental investigation of it in a diesel engine revealed an increase in engine torque and BTE, while emissions such as CO and NO_x were shown to be reduced. But very few attempts have been made on the usage of waste transformer oil as an engine fuel substitute. [2] experimentally investigated the waste transformer oil without any processing has been directly blended with diesel and used as a fuel in the engine and it was reported the increase in brake thermal efficiency with significant reduction of smoke.

In this work, waste transformer oil collected from diesel-electric power station located in the Annamalai University campus has been decidedly chosen for necessary processing and utilized as an engine fuel substitute. Transformer oil, stable under all conditions of use and storage can be blended with petrol-based fuel readily. The oil used in this study is golden brownish color with high viscosity and having higher hydrocarbon compounds as a major constituent. The waste transformer oil cannot be used directly on the engine because of its high viscosity which could result in poor atomization. The solution to the problem has been approached in several ways, such as preheating the oil, blending them with diesel, pyrolysis, traditional base-catalyzed trans-esterification and catalytic cracking. In this work, traditional base-catalyzed trans-esterification has been implemented to reduce the viscosity of the waste transformer oil and thereby converting it into TWTO (trans-esterified waste transformer oil) as fuel for diesel engine.

The objective of the work is to study the influence of injection timing on the performance, emission and combustion characteristics of a DI diesel engine using TWTO as a fuel. The TWTO obtained after traditional base-catalyzed trans-esterification process is subject to FTIR (Fourier transform infrared) analysis to identify the functional group and compositional analysis. The physical properties of TWTO such as specific gravity, kinematic viscosity, flash point, gross calorific value, density and cetane number have also been obtained.

2. Traditional base-catalyzed trans-esterification procedure

The fuel used in this study was extracted from the trans-esterification of waste transformer oil, purified from dust, metal particles, gum-type materials and other impurities have been treated with methanol (CH_3OH) catalyzed by potassium hydroxide (KOH). A titration was performed to determine the amount of KOH needed to neutralize and break the long chain hydrocarbons present in the waste transformer oil. The amount of KOH needed as catalyst for every liter of waste transformer oil was determined as 12 g. For trans-esterification, 210 ml CH_3OH plus the required amount of KOH were added for every liter of waste transformer oil, and the reactions were carried out at 45 °C. One liter of waste transformer oil is first subjected to 65 °C for 30 min and then 12 g of KOH, which is dissolved in 210 ml of CH_3OH is poured into one liter of waste transformer oil. The water wash process was performed by using a sprinkler which slowly sprinkled water into the oil container until there was an equal amount of water and oil in the container. The water hydrocarbon mixture was then agitated gently for 20 min, allowing the water to settle out of the hydrocarbon mixture. After the mixture had settled, the water was drained out. The properties of the trans-esterified waste transformer oil and diesel are shown in Table 1.

Table 1 Properties of trans-esterified waste transformer oil and diesel.

Property	Measurement standards	WTO	Diesel	100% TWTO
Specific gravity @ 27 °C	ASTM D1298	0.8512	0.8298	0.8503
Kinematic viscosity @40 °C in CSt	ASTM D445	11.06	2.57	10.80
Flash Point in °C	ASTM D92	144	37	136
Fire Point in °C	ASTM D92	152	40	143
Gross calorific value in kcal/kg	ASTM D240	10,218	10,738	10,233
Density@15 °C in gm/cc	ASTM D1298	0.8604	0.8072	0.8494
Cetane number	ASTM D976	52.7	52	49.1